Analog-to-Digital Converters Basics

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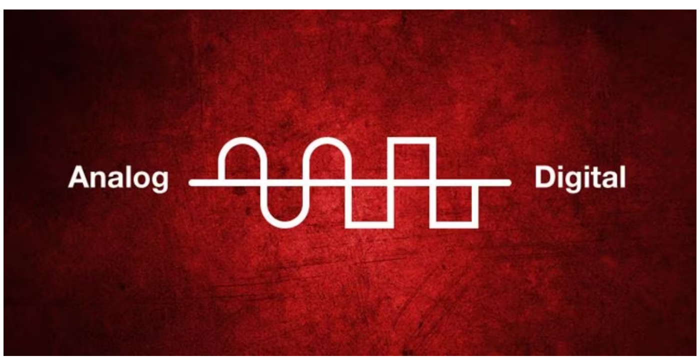

Published By

[Analog-to-digital converters (ADCs)] are an important component when it comes to dealing with digital systems communicating with real-time signals. With IoT developing quickly to be applied in everyday life, real-world/time signals have to be read by these signals that have a continuous sequence with continuous values (there are some cases where it can be finite). These types of signals can come from sound, light, temperature and motion. Digital signals are represented by a sequence of discrete values where the signal is broken down into sequences that depend on the time series or sampling rate (more on this later). The easiest way to explain this it through a visual! Figure 1 shows a great example of what analog and digital signals look like.

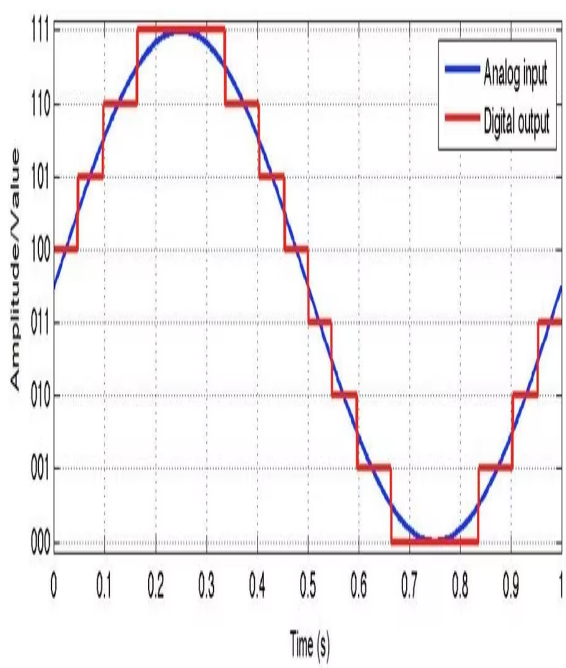

Figure 1: A continuous signal (analog) turning into a digital signal. (Source: Waqas Akram – Quantization in ADCs)

and finally set binary values and send it to the system to read the digital signal. Two important aspects of the ADC are its sampling rate and resolution.

What is the ADC Sampling Rate/Frequency?

The ADC's sampling rate, also known as sampling frequency, can be tied to the ADC's speed. The sampling rate is measured by using "samples per second", where the units are in SPS or S/s (or if you're using sampling frequency, it would be in Hz). This simply means how many samples or data points it takes within a second. The more samples the ADC takes, the higher frequencies it can handle.

One important equation on the sample rate is:

$f_s = 1/T$

Where,

f_s = Sample Rate/Frequency
T = Period of the sample or the time it takes before sampling again

For example, in Figure 1, it seems f_s is 20 S/s (or 20 Hz), while T is 50 ms. The sample rate is very slow, but the signal still came out similar to the original reconstructed, it differs greatly from the original image/signal caused from sampling.

If the sampling rate is slow and the frequency of the signal is high, the ADC will not be able to reconstruct the original analog signal which will cause the system to read incorrect data. A good example is shown in Figure 2.

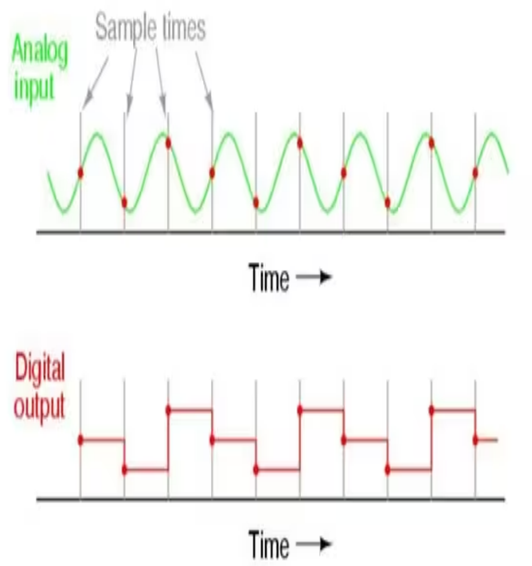

Figure 2: An example of how aliasing happens. (Source: Tony R. Kuphaldt - Lessons in Electric Circuits)

In this example, you can see where the sampling occurs in the analog input signal. The output of the digital signal is not at all close to the original signal as the sampling rate is not high enough to original analog signal. The following equation is used to find the Nyquist frequency:

$f_{Nyquist} = 2f_{Max}$

Where,

$f_{Nyquist}$ = Nyquist frequency
f_{Max} = The max frequency that appears in the signal

For example, if the signal that you input into the digital system has a max frequency of 100 kHz, then the sampling rate on your ADC needs to be equal or greater than 200 kS/s. This will allow for a successful reconstruction of the original signal.

It is also good to note that there are cases where outside noise can introduce unexpected high frequency into the analog signal, which can disrupt the signal because the sample rate couldn't handle the added noise frequency. It is always a good idea to add an anti-aliasing filter (**low-pass filter**) before the ADC and sampling begins, as it can prevent unexpected high frequencies to make it to the system.

How is Resolution of ADC Determined?

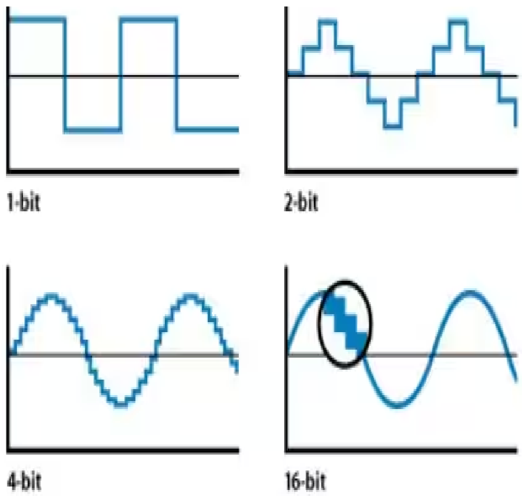

Figure 3: Example on how resolution affects the digital signal. (Source: Apple Inc – Soundtrack Pro 3: Audio Fundamentals)

If you need accurate voltage level for your system to read, then the bit resolution is important to know. The resolution depends on both the bit length and the reference voltage. These equations help you figure out the total resolution of the signal that you are trying to input in voltage terms:

Sample ADC Resolution Formula:

Step Size = V_{Ref}/N

Where,

Step Size = The resolution of each level in terms of voltage n = Bit Size

For example, let's say that a sine wave with a voltage range of 5 needs to be read. The ADC has a bit size of 12-bit. Plug in 12 to n on equation 4 and N will be 4096. With that known and the voltage reference set to 5V, you'll have: Step Size = 5V/4096. You will find that the step size will be around 0.00122V (or 1.22mV). This is accurate as the digital system will be able to tell when the voltage changes on an accuracy of 1.22mV.
If the ADC was a very small bit length, let's say only 2 bits, then the accuracy would reduce to only 1.25V, which is very poor as it will only be able to tell the system of four voltage levels (0V, 1.25V, 2.5V, 3.75V and 5V).

Figure 4 shows common bit length and their number of levels. It also shows what the step size would be for a 5V reference. You can see how accurate it gets as the bit length increases.

Figure 4: Bit Length and their number of levels and step size for a 5V reference range.

With understanding both the resolution and the sample rates of the ADC, you can see how important it is to know these values and what to expect from your ADC.

Analog Devices To Consider

Analog Devices have a great range of ADCs that are high quality and reliable that can be general or special purpose converters. Here are a few to consider for your next design:

AD7175-2 (Max Resolution: 24-bit | Max Sample Rate: 250 kSPS)

The AD7175-2 is a Delta-Sigma analog-to-digital converter for low bandwidth inputs. It has low noise, fast settling, multiplexed, 2-/4-channels that has a maximum channel scan rate of 50 kSPS (20μs) for fully settled data. The output data rates can range from 5 SPS to 250 kSPS. You can also configure an individual setup for each analog input channel in use and can have a max of 24-bit resolution. Applications include: process control (PLC/DCS modules), temperature

AD9680 (Max Resolution: 14-bit | Max Sample Rate: 1.25 GSPS)

This ADC has a wide full power bandwidth that supports IF sampling of signals up to 2GHz. It has four integrated wideband decimation filters and its numerically controlled oscillators (NCO) blocks supporting multiband receivers. With its buffered inputs with programmable input termination, it eases filter design and implementation. Applications include: **communications**, general-purpose software radios, ultrawideband satellite receivers, instrumentation, **radars** and much more.

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AD7760 (Max Resolution: 24-bit | Max Sample Rate: 2.5 MSPS)

AD7760 is a high-performance sigma-delta ADC that combines input bandwidth and high speed with benefits of a sigma-delta conversion to achieve a performance of 100 dB ANR at 2.5 MSPS, making it ideal for high speed data acquisition. It can simplify the design process with its wide dynamic range

Looking for a Digital-to-Analog Converter (DAC) instead? Read **how to choose the best DAC for your project here**.

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